Air Quality Impacts from NOx Emissions of Two Potential Marine Vessel Control Strategies in the South Coast Air Basin

Final Report

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Prepared by the California Air Resources Board and the South Coast Air Quality Management District in Consultation with the Deep Sea Vessel/Shipping Channel Technical Working Group

California Environmental Protection Agency
Air Resources Board

South Coast
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LIST OF ACRONYMS & ABBREVIATIONS

To aid the reader, the following list of acronyms and/or abbreviations used throughout the document is provided.

Acronym	Explanation
ARB	Air Resources Board
BATS	Automated Sequential Samplers
BNL	Brookhaven National Laboratory
CATS	Passive Samplers
g/kWh	Grams per kilowatt-hour
NOx	Oxides of Nitrogen
PMCP	Perfluoromethylcyclopentane
PMCH	Perfluoromethylcyclohexane
PDCH	Perfluoro-1,2-dimethylcyclohexane
PTCH	Perfluorotrimethylcyclohexane
PDCB	Perfluorodimethylcyclobutane
POLA	Port of Los Angeles
POLB	Port of Long Beach
SCAB	South Coast Air Basin
SCAQMD	South Coast Air Quality Management District
SCOS97-NARSTO	1997 Southern California Ozone Study-North American Research Strategy for Tropospheric Ozone
SIP	State Implementation Plan
TWG	Deep Sea Vessel/Shipping Channel Technical Working Group
UAM	Urban Airshed Model
U.S. EPA	United States Environmental Protection Agency

EXECUTIVE SUMMARY

The Ports of Long Beach and Los Angeles, with ready access to Southern California's extensive rail and road network, are two of the busiest ports in the nation. In 1998, the Ports had a combined container volume of 7.3 billion TEUs (1 TEU is equivalent to one 20-foot cargo container unit) and moved goods worth 160 billion dollars. The Ports are integral players in the Southern California economy and are planning for continued growth over the next 20 years as the global marketplace expands and results in increased international trade and commerce.

The coastal waters off Southern California are also key operational waters for the United States Department of the Navy including the Pt. Mugu Sea Test Range. Aside from providing critical training, research and development, test and evaluation, and other operational assets, the Department of the Navy represents a $9.5 billion direct economic contribution to the San Diego economy, and a nearly $2 billion direct economic contribution to the Ventura County economy. These installations exist in their present location largely due to their proximity to these operationally-realistic and coastal region conditions.

The emissions from ocean-going ships contribute to the air quality problems that have long plagued Southern California. The strategy to improve air quality is identified in the 1994 Ozone State Implementation Plan (SIP). To address the emissions from marine vessels, it includes control measure M-13 "National and International Emission Standards for Marine Vessels" that is assigned to the federal government and, among other things, commits to achieving approximately a 30% reduction in the cruising emissions from ocean-going ships in 2010. M-13 did not mandate a particular control strategy to realize these reductions but did identify two possible operational controls-voluntary speed reduction and relocation of the existing commercial shipping lane to an area further offshore.

The Deep Sea Vessel/Shipping Channel Technical Working Group (TWG) conducted a comparative technical analysis of the air quality impacts between two potential operational control strategies for submittal to the United States Environmental Protection Agency (U.S. EPA). Based on the technical analysis, which relied both on data collected from a tracer dispersion study of ship emissions and model simulations of the emissions of NOx from offshore shipping and the resultant net onshore mass flux, the TWG reached the following conclusions:

- Reducing the speed at which ships travel reduces the flux of NOx emissions that reach onshore. The magnitude of the reductions is dependent upon the degree of speed reduction and the distance traveled at the reduced speed with the reductions proportional to the distance traveled and the reduced speed.

- The impact of moving the shipping lane further offshore on the onshore flux of NOx emissions is more sensitive to meteorological conditions. On some days there is an emission reduction benefit and on other days there is a disbenefit, depending on the specific weather and wind conditions.

I

INTRODUCTION AND BACKGROUND

This report summarizes a comparative technical analysis of the air quality impacts for two potential marine vessel control strategies originally included in a proposed 1994 Federal Implementation Plan and subsequently incorporated in the South Coast 1994 Ozone State Implementation Plan (SIP). This analysis was conducted by the Deep Sea Vessel/Shipping Channel Technical Working Group (TWG) for submittal to the United States Environmental Protection Agency (U.S. EPA). The analysis was undertaken with the expectation that the U.S. EPA would incorporate the results of the analysis in a public process to select an appropriate strategy for implementing the SIP measure for marine vessels (M-13) that was identified in the 1994 Ozone SIP as a federal assignment. The TWG only assessed the air quality impacts between the two control strategies and did not address other issues that will need to be considered when formal rule-making action takes place such as cost-effectiveness, technical and commercial feasibility, and national security impacts. In this report, we provide a short review on the need for emission reductions from marine vessels, the formation of the technical working group and the technical approach used for the comparative analysis as well as the results from that analysis. Finally, we provide our findings and recommendations for U.S. EPA to consider in its deliberation on control strategies for marine vessels.

A. BACKGROUND

The need for a comparative technical analysis between the two potential control strategies became apparent during discussions on feasible ship emission reduction strategies for the South Coast Air Basin (SCAB) and ultimately led to the formation of the TWG. To provide perspective, below we briefly describe the need for emission reductions from marine vessels, the federal consultative process that generated a study to collect additional technical data to improve the understanding of the impacts of ship emissions, and the formation and goals of the TWG.

<u>Need for Reductions from Marine Vessels</u>

The SCAB violates the federal ozone standard more frequently, and by a greater margin, than any other area in California. The strategy to attain the federal standard for ozone in the SCAB is laid out in the 1994 Ozone SIP, and relies on control measures that affect the entire range of emission categories, including marine vessels. To address the emissions from marine vessels, the 1994 Ozone SIP includes control measure M-13 "National and International Emission Standards for Marine Vessels" that is assigned to the federal government and commits to achieving a 9 ton per day NOx emission reduction in 2010 in the SCAB based on a projected 1990 baseline inventory.

M-13 identifies several possible options for achieving the needed emission reductions from marine sources, including national and international emission standards, and operational controls such as moving commercial ocean ships further offshore and reducing ship speeds. [1]

Public Consultative Process

While U.S. EPA did not agree that states have the authority to make a SIP assignment to U.S. EPA, the Agency agreed that the Federal government should voluntarily help achieve emission reductions from sources beyond the regulatory authority of the State, particularly in view of the unique reduction needs of the South Coast, the only ozone nonattainment area classified as "extreme" under the 1990 federal Clean Air Act Amendments. As such, when the U.S. EPA approved the 1994 Ozone SIP in 1997, the U.S. EPA committed itself to a "Public Consultative Process" (PCP) to work with the various stakeholders to investigate adoption and implementation of the measures to achieve the emission reductions assigned to the federal government (62 FR 1150-1187). Under the PCP, U.S. EPA held a series of stakeholder meetings between November 1996 and May 1998 to discuss strategies to reduce pollution associated with the marine vessel sector. The federal PCP was formally concluded in 1999; however, U.S. EPA committed to continue a focused cooperative effort to agree upon the best approach for achieving reductions from marine vessels. As part of a settlement agreement with several environmental groups, U.S. EPA has agreed to propose rulemaking for the federal assignments by the end of calendar year 2000 and complete final rulemaking in calendar year 2001 (64 FR39923-27).

During the course of the PCP meetings to address marine emissions, three workgroups were formed including the Deep Sea Vessel/Shipping Channel workgroup. This workgroup focused on control strategies for deep sea vessels. After numerous discussions on various control options for deep sea vessels, the Deep Sea Vessel/Shipping Channel workgroup focused on two plausible strategies for reducing emissions using voluntary operational controls – reduce ship speeds and/or relocation of the existing shipping lane. These strategies were originally identified in the 1994 Ozone SIP as potential candidates for consideration. Both of these operational controls are potentially controversial and the workgroup desired sound technical data on which to base any decision.

Tracer Dispersion Study

To gather the necessary technical data, the Deep Sea Vessel/Shipping Channel workgroup prepared a Memorandum of Agreement (MOA) to implement a study to examine trajectories of marine vessel air emissions. The study, entitled "Tracer

[1] The South Coast Air Quality Management District updated the Air Quality Management Plan of the South Coast Air District in 1997. In this update, the M-13 control strategy was unchanged but the emission reduction commitment was increased to 15 tons per day, reflecting an increased estimate of the total NOx inventory for marine vessels that was made in 1996. On April 10, 2000, U.S. EPA finalized approval of the ozone portion of the revised plan. (65FR18903)

Dispersion Study of Shipping Emissions During SCOS-NARSTO" (tracer study), was designed to gather sound scientific data on which to base decisions on the transport of emissions from vessels using the existing and an alternative shipping channel. Signatories to the MOA included the U.S. EPA, the ARB, the South Coast Air Quality Management District (SCAQMD), the United States Navy (U.S. Navy), the Ports of Long Beach and Los Angeles, the Steamship Association of Southern California and the Pacific Merchant Shipping Association, each contributing monies to fund the $400,000 tracer study. Two contractors were selected to conduct the technical aspects of the study, Brookhaven National Laboratory and Tracer Environmental Sciences and Technologies, Inc. (Tracer ES&T) The primary objective of the study was to obtain direct evidence regarding the relative impacts of pollutants emitted from offshore sources on onshore air quality, specifically from the current and an alternative proposed shipping lane. The study was also designed to provide valuable data to validate existing meteorological models and to link the study with the 1997 Southern California Ozone Study-North American Research Strategy for Tropospheric Ozone (SCOS97), a large-scale intensive research effort intended to generate updated data regarding ozone episodes in southern California. Parallel to this effort, U.S. EPA contracted with Arcadis, Geraghty, & Miller to assess the benefits of future emission standards and alternative strategies, including a strategy to reduce ship speed.

Deep Sea Vessel/Shipping Channel Technical Working Group

As part of a commitment to participate in the federal consultative process the Air Resources Board (ARB) convened a technical working group in the summer of 1998. The goal of this working group, the "Deep Sea Vessel/Shipping Channel Technical Working Group" (TWG) was to ensure the analysis of the scientific data results in a clear understanding of the air quality benefits of two alternatives under consideration - relocation of the existing shipping lanes and voluntary speed reduction. Members include those parties that had participated in the Deep Sea Vessel/Shipping channel workgroup that was established under the federal consultative process. Participation was open to the public, but invitations were initially extended to representatives of the SCAQMD, ARB, U.S. EPA, the Ports of Los Angeles and Long Beach, the U.S. Navy, Pacific Merchant and Shipping Association, Steamship Association of Southern California, the City of Los Angeles, the U.S. Coast Guard, and the Coalition for Clean Air.

The primary goal of the TWG was to perform a technical analysis of the two alternatives, relocation of the existing shipping lanes and voluntary speed reduction, that incorporates the results of the tracer study. The TWG met approximately bi-monthly over a 2-year period beginning in June 1998. At the meetings the members discussed and reached consensus on the approach for the comparative technical analysis of the air quality impacts of the two alternative operational controls under consideration, the data inputs (emissions inventory) for the technical analysis, analysis of the tracer study results, and the recommendations for U.S. EPA. As mentioned earlier, the TWG only considered the air quality impacts and did not address the other factors that may need to be considered when a decision is made regarding the most appropriate operational control for marine vessels.

References

Federal Register, Volume 62, pages 1150-1187, Approval and Promulgation of Implementation Plans; California-Ozone, January 8, 1997.

Federal Register, Volume 64, pages 39923-39927, Approval and Promulgation of State Implementation Plans; California-South Coast, July 23, 1999.

Federal Register, Volume 65, pages 18903 – 18906, Approval and Promulgation of State Implementation Plans; California – South Coast, April 10, 2000.

II

POTENTIAL EMISSION CONTROL STRATEGIES

The two key operational emission control strategies that emerged during the discussions on emission controls for deep sea marine vessels were a voluntary speed reduction option and relocation of the existing shipping lanes further offshore. Both of these options involve modifications to the way ships are normally operated as a means to generate emission reductions. In this chapter, we briefly describe the two operational control strategies and provide a brief synopsis of the technical approach used to compare the air quality impacts between the two options.

A. VOLUNTARY SPEED REDUCTION

Reducing the speed of a vessel results in emission reductions from the propulsion engines. At reduced speeds a ship requires less power from the engine to move the ship, which tends to decrease emissions. While reducing the speed also results in more time to travel a given distance, the overall emissions are lower because the emissions associated with the increased travel time is less significant (linear with ship speed) than the decreased power requirements (power is approximately proportional to the ship speed, cubed) (ARCADIS, May 6, 1999).

Ships traveling along the existing shipping lanes travel at various speeds, the speed being dependent on several variables. Data collected on ships arriving at and leaving the Ports of Long Beach and Los Angeles for a 60 day period in 1998 (September 22-November 22, 1998) reveals a range of speeds. In Table II-1 we summarize the average cruising speed for 3 ship types. These speeds were recorded at the 25-mile line off shore and for all practicable purposes one can assume that at that point, the ships are operating at cruising speed. (McKenna, January 6, 1999) Once the ships enter the precautionary zone, an area approximately 5 miles from the breakwater, the ships are required to travel at a speed limit of 12 knots.[2] About one mile from the breakwater the ships slow to about 5 knots to take on a pilot and then maneuver into the harbor at low speeds.

[2] The emissions impacts from this voluntary speed reduction requirement that was instituted on March 1, 1994 was not accounted for in the projected 1990 baseline inventory used in the 1994 Ozone SIP, but was reflected in the inventory used in the most recent 1997 SIP revision for the South Coast. In the 1997 SIP, we estimate there was approximately a 6 percent reduction (about 1.7 tons per day) in the projected baseline emissions that can be attributable to the precautionary zone speed limit. See Appendix B for methodology.

Table II-1
Average Speed by Ship Type

Ship Type	Cargo Carriers	Passenger	Liquid Bulk Carriers
Average MAREX Speed, knots	17.9	13.60	13.68
Average Design Speed, knots	19.58	20.40	15.31
Count	1341	111	231
Average Count per day	22	2	4

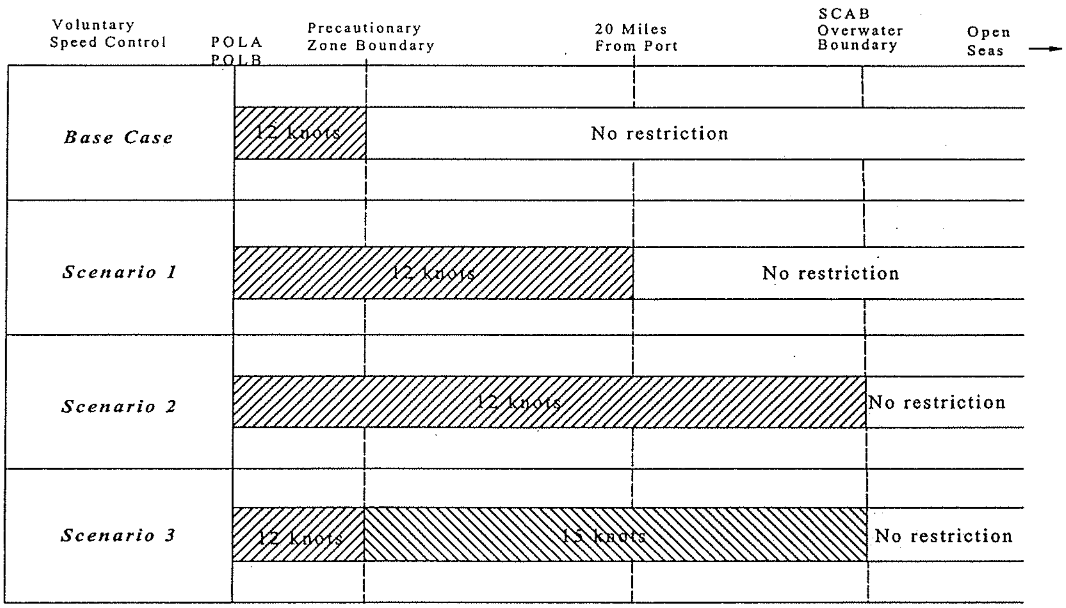
Notes: Cargo Carriers include container ships, auto carriers, breakbulk etc. The average MAREX speed was calculated from data collected by the Marine Exchange on ships traveling the existing shipping lane from September 22 to November 22, 1998. The average design speed was obtained from Lloyd's Maritime Information Services, Inc.

As indicated above, reducing the speeds below these observed values will result in emission reductions. The TWG explored various speed reduction scenarios considering the reduction in speeds, the distance over which that lower speed would be in effect, and the reasonableness of implementing the speed reductions. Three test cases were identified to be evaluated in the comparative analysis of the air quality impacts between the two operational controls. While the TWG acknowledged that the U.S. EPA will need to take into consideration many factors when designing a control strategy, these test cases were believed to bracket the range of potential speed controls that would ultimately be considered by the U.S. EPA.

The first test case or scenario was extension of the precautionary zone speed limit of 12 knots to 20 miles offshore. In this scenario, ships that had been traveling in excess of 12 knots in the waters past the precautionary zone would reduce their speeds to 12 knots. The second speed reduction scenario is to extend the 12 knot precautionary speed limit to the overwater boundary[3] of the SCAB waters; and last, the third test case was to require a speed limit of 15 knots between the overwater boundary of the SCAB and the precautionary zone. In each of the scenarios, it is assumed that ships traveling in excess of the speed limit would reduce their speeds to that limit, and that ships traveling at speeds lower than the speed limit would not increase their speed to the limit specified. It is also assumed that no other changes in the ship operational procedures would occur, i.e. ships would not speed up beyond the restricted area to make up time and ship speeds both while traveling in the breakwater and maneuvering within the ports would remain the same. For illustrative purposes, in Figure II-1, we have provided a simplistic representation of the base case and 3 speed reduction scenarios.

[3] The overwater boundary of the SCAB is delineated by straight line extensions perpendicular to the coast of the overland SCAB boundaries (the Ventura-Los Angeles County line to the north and the San Diego-Orange County line to the south) out to the point where the straight line extensions intersect with the California Coastal water boundary – approximately 100 miles offshore in the SCAB.

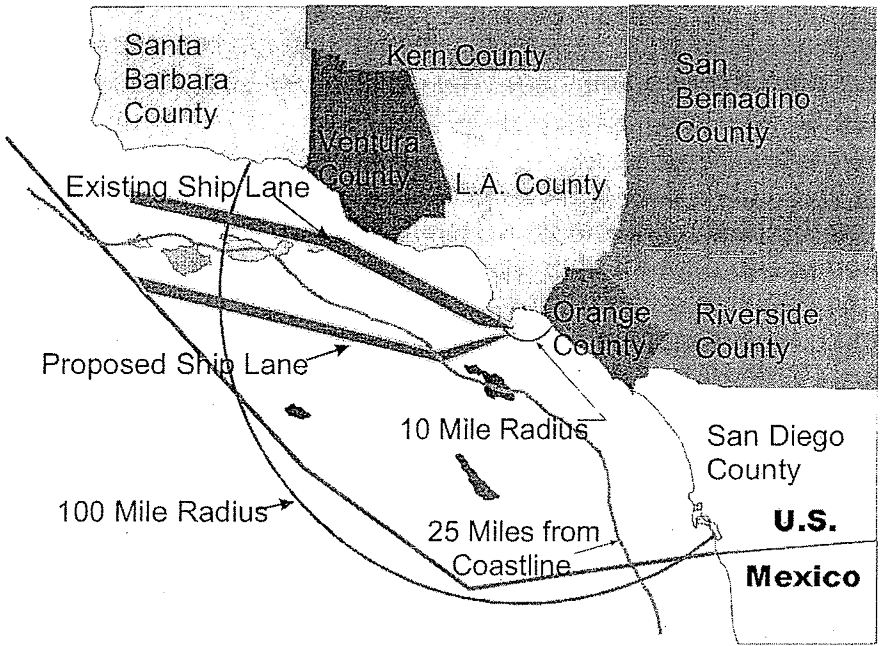
Figure II-1
Voluntary Speed Reduction Test Scenarios



B. RELOCATION OF THE SHIPPING LANE

The second operational control evaluated by the TWG is relocation of the shipping lane to a region further offshore than the existing lane. The approved 1994 Ozone SIP included a commitment to evaluate movement of the shipping lane based on the premise that movement of the shipping channel further off the coast would reduce the impact of marine vessel emissions on air quality in the SCAB. The existing shipping lane traverses the coast at approximately 10-15 miles offshore. While the 1994 SIP did not specify a location for a relocated shipping lane, it was originally proposed in the 1994 Federal Implementation Plan (FIP) for the South Coast Air Basin to move the shipping lane to further than 25 miles offshore (approximately 6-10 miles off the Channel Islands). Several of the TWG members indicated that the proposed "FIP" shipping lane may not be realistic due to a sharp "dog-leg" in the path directly outside the port and the fact that it passes through the U.S. Navy test range at Pt. Mugu. However, because the tracer study released the tracer gases in both the existing shipping channel and the proposed FIP shipping lane, the TWG agreed, for the purposes of the comparative analysis, to limit the comparison of the emissions impacts to these two tracks. The proposed and existing shipping lanes are depicted in Figure II-2 below.

Figure II-2
Existing and Proposed Shipping Lanes for the Ports of Los Angeles and Long Beach



During several of the discussions on relocation of the existing shipping lane, the TWG identified parameters that may change if ships are required to travel in a shipping lane further offshore. These included speeding up to make up the additional time needed to travel a longer route and ships potentially having to idle outside the missile test range prior to passage. However, the TWG agreed that trying to predict any changes in operational patterns was outside the scope of this comparative analysis and that for the analysis being prepared by the TWG, it will be assumed that ship operational characteristics will be the same for ships traveling in the proposed and existing shipping lanes, with the only difference being the travel route.

C. TECHNICAL ANALYSIS APPROACH

To evaluate the air quality impacts from the two potential control strategies, the TWG: 1) used the results of the tracer tests to provide a measurement based assessment of the onshore impacts between the proposed and existing shipping lanes; and 2) used an air quality dispersion model with a windfield that has been validated with the tracer data to perform a comparative analysis between the two control options by quantifying the differences in ship NOx emissions that reach onshore in the SCAB. September 4th and 5th, 1997 were selected for the model simulations since they were both a tracer release event and an episode day for the SCOS97. Photochemical modeling was outside the scope of this effort due to the lack of a complete emission inventory and time considerations, but will be used when the SCAQMD develops a comprehensive AQMP in the 2001 timeframe. At that time, photochemical and other air quality models will be used to assess both the ozone and fine particulate matter impacts from all sources, including ships.

To accomplish these assessments, several tasks were undertaken to provide the necessary technical data. These tasks are briefly described below and in more detail in the following chapters.

Baseline Emission Inventory: Baseline day-specific ship NO_x emission inventories were developed based on the best available data. Information on individual ship type, speed, travel route, and composite data for ship types for stack height and temperature were used to generate the baseline inventory for August 3-7, 1997. The period August 3-7, 1997 was selected as representative because high ozone levels typical of a high ozone summer day were measured during that time period, and the ships operating in the SCAB waters during that period were a representative cross section of ships that call at southern California ports during the summer ozone season.

Emission Inventory for Proposed Control Options: NO_x emission inventories were created for both the proposed and existing (baseline) shipping lanes as well as for the three speed control scenarios selected for evaluation using the same methodology as for creating the baseline emission inventory.

Gridded Emission Inventory: The baseline and proposed control option inventories were gridded using an ARB shipping emissions model. This model grids ships as moving point sources and provides estimates of hourly resolved emissions for each 2km grid cell.

Tracer Data QA/QC and Normalization: Because of unforeseen problems, adequate funds were not available to have the contractor complete the analysis of the tracer data as originally planned. In lieu of generating additional funding to complete the analysis, and to ensure that the original objectives of the tracer study were met, ARB staff completed the analysis in consultation with the TWG. This work entailed reviewing the data generated by Brookhaven to verify its completeness and clarity and to review the data for outliers or otherwise questionable or non-representative data. The data were also normalized to account for differences in tracer release amounts, chemical characteristics, and ship speeds.

Assessment of Tracer Results for the Existing and Proposed Shipping Lanes: To compare the atmospheric impacts for releases in the existing and proposed shipping lanes, the normalized average station tracer peak concentrations for the morning and afternoon tracer releases were calculated for Ventura County, SCAQMD, and San Diego County on each of the tracer release days. The ratios of impacts (average normalized station peaks) from the proposed shipping lane to those in the existing lane for the SCAQMD were then developed for each of the comparable releases. Ratios less than 1.0 imply greater dispersion from the proposed lane and ratios greater than

1.0 imply less dispersion from the proposed lane. Ratios near 1.0 imply similar dispersion for the two lanes.

Windfield Preparation and Validation: A windfield validation analysis was included as part of the windfield development process and peer review was provided by a group of meteorologists and air quality modelers with expertise in the southern California region. To validate the windfield, the observed concentrations from the tracer experiment on September 4, 1997 were compared with the simulation results using the CALMET meteorological model and the CALGRID air quality model. Two approaches were used: 1) comparison of the relative distribution of mass from tracers released offshore through vertical planes defined from line segments representing each of Ventura, Los Angeles, Orange, and San Diego Counties; and 2) comparison of observed and simulated tracer distribution ratios (X/Q)

Model Simulations: An Eulerian air quality modeling system (CALMET meteorological model and CALGRID air quality model) was applied to two episode periods (August 4-7, 1997 and September 4-5, 1997) to assess the relative impacts of shipping emissions from the shipping lane and speed scenarios representing each control strategy. For each of the control scenarios the emissions of NOx from offshore shipping were simulated and the net onshore mass flux into the SCAB was calculated. Comparisons of the mass flux among the scenarios were made for each day of the two episodes simulated.

Comparative Analysis: The results from the modeling analysis and tracer analysis were compared to arrive at qualitative conclusions regarding the air quality impacts of the two shipping control strategies. Results of the tracer analysis allowed for comparison between the proposed and existing shipping lanes by providing an estimate of the dispersion onshore of NOx emissions released from transiting ships. The modeling simulations provided for a comparison between the two proposed control strategies (movement of the shipping lanes and voluntary speed reductions) as well as a comparison between the 3 speed reduction scenarios that were identified.

Throughout the working group process, a number of issues were raised on which the TWG reached consensus that the issues were beyond the scope of the comparative analysis being conducted by the TWG. These issues are described in Appendix A "Scope of Analysis."

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